REALM PROJECT

REopening Archives, Libraries, and Museums

Briefing: Vaccines, Variants, and Ventilation

A Briefing on Recent Scientific Literature Focused on SARS-CoV-2 Vaccines and Variants, Plus the Effects of Ventilation on Virus Spread

Dates of Search: 01 January 2021 through 16 August 2021

Published: 2 September 2021

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INTRODUCTION

Purpose of This Briefing

- Access to the latest scientific research is critical as libraries, archives, and museums (LAMs) work to sustain modified operations during the continuing severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic.
- As an emerging event, the SARS-CoV-2 pandemic continually presents new challenges and scientific questions. At present, **SARS-CoV-2 vaccines and variants in the US** are two critical areas of focus. The effects of **ventilation-based interventions on the spread of SARS-CoV-2** are also an interest area for LAMs. This briefing provides key information and results from the latest scientific literature to help inform LAMs making decisions related to these topics.

How to Use This Briefing: This briefing is intended to provide timely information about SARS-CoV-2 vaccines, variants, and ventilation to LAMs and their stakeholders. Due to the evolving nature of scientific research on these topics, the information provided here is not intended to be comprehensive or final. As such, this briefing should be used in conjunction with other timely resources to ensure decision-making reflects the latest scientific understanding. Continual re-evaluation of SARS-CoV-2 policies is highly recommended as new scientific discoveries are published.

About This Briefing

- Battelle conducted a systematic search of scientific literature about SARS-CoV-2 vaccines, variants, and ventilation. This briefing summarizes those findings.
- Research questions:
    1. What implications does SARS-CoV-2 vaccination in the US have for public health interventions and policies, especially related to indoor environments?
    2. How do SARS-CoV-2 variants currently circulating in the US differ from the original strain in terms of spread, transmissibility, surface attenuation, and effectiveness of public health interventions?
    3. What effects do ventilation and ventilation-based interventions (e.g., heating, ventilation, and air conditioning systems (HVAC)) have on the spread of SARS-CoV-2 in indoor environments?
- Dates of search: 01 January 2021 to 16 August 2021. Newest items labeled "[New]"
- Additional information about the methods used to conduct the literature search and create this briefing is included later in the document.

About REALM

REopening Archives, Libraries, and Museums (REALM) is a research project conducted by OCLC, the Institute of Museum and Library Services (IMLS), and Battelle to produce and distribute science-based COVID-19 information that can aid local decision-making regarding operations of archives, libraries, and museums.

View reports published by REALM.

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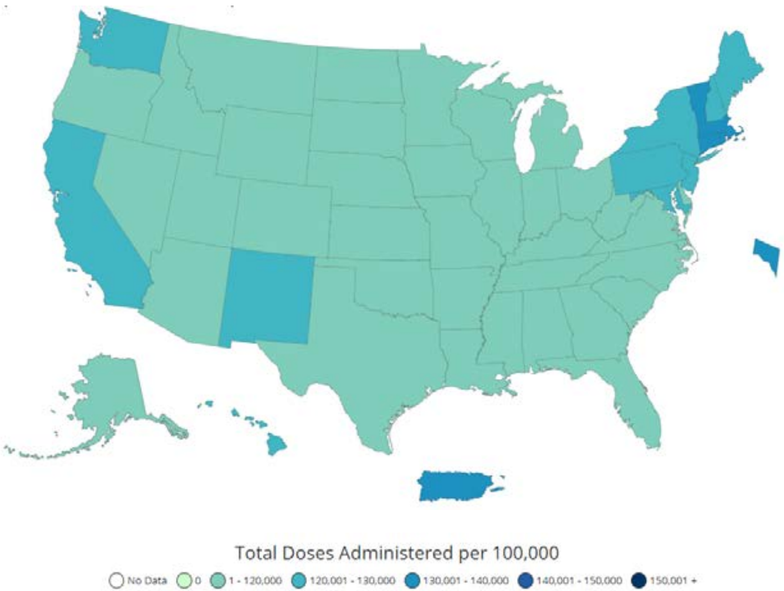
BACKGROUND INFORMATION: VACCINES AND VARIANTS

SARS-CoV-2 Vaccines

- The CDC reports updated vaccination numbers daily on a COVID-19 data tracker. [1]
- [New] Three safe and effective vaccines are being distributed, two under the US FDA Emergency Use Authorization and one with full FDA approval: [2, 3][New]
  - Pfizer-BioNTech: 2-dose series, 21 days apart [4]
    - [New] Full FDA approval on 23 August 2021 for people ages 16 and older [3]
  - Moderna: 2-dose series, 28 days apart [5]
  - Janssen (Johnson & Johnson) (J&J): Single dose [6]
- CDC recommends individuals get the first vaccine that is available for their age group. [4]
- The US government has made vaccines free, and they are widely available now. [7]

Total Doses Administered Reported to the CDC by State/Territory per 100,000 of the Total Population (as of 31 August 2021)



**Vaccination rates by county are also available

To find local vaccination sites: visit Vaccines.gov, text a zip code to 438829, or call 800-232-0233.

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SARS-CoV-2 Vaccines

- CDC recommends that everyone age 12 or older receive a COVID-19 vaccine.[7]
  - On 23 April 2021, CDC and FDA recommended use of the J&J vaccine after a brief pause in the US. Both agencies noted women 50 years of age and younger should be made aware of an increased risk of a rare adverse event that involves blood clots. [6]
  - CDC noted increased reports of heart-related inflammation in teens and young adults after COVID-19 vaccination, but COVID-19 vaccination is still recommended for everyone age 12 or older because benefits continue to outweigh risks.[4]
  - On 13 July 2021, FDA reported an observed increased risk of Guillain-Barré Syndrome (GBS) after J&J vaccination. 100 cases were reported, out of 12.5 million doses administered. FDA has still granted emergency use authorization for the J&J vaccine, but vaccine fact sheets now note that adverse events suggest increased risk of GBS and J&J vaccine recipients with GBS symptoms should seek medical attention.[8]
- CDC has indicated that people who are fully vaccinated can resume some activities they stopped due to the pandemic. CDC continues to review infection rates across the country and release guidance on precautions that both vaccinated and non-vaccinated people should take to stop the spread of COVID-19.[9] Lists of what may and may not be safe to change after full vaccination are on the CDC website.

Variants of SARS-CoV-2

What is a Variant?

- **Viruses inherently replicate, which can result in genetic changes or mutations**. After enough mutations occur, the new version is called a variant. As expected, multiple SARS-CoV-2 variants have been found in the US and abroad during this pandemic.
- Sometimes new variants emerge and disappear, and other times new variants emerge and persist.[10]

Types of Variants[11]

- There are three types of variants. The types differ based on the possibility of the variant to affect people negatively, such as increased transmissibility. In order from least to most negative effects:
  - Variants of Interest (VOI)
  - Variants of Concern (VOC)
  - Variants of High Consequence (VOHC)
- As of this report, in the US there are four VOI, four VOC, and zero VOHC.[11]

Why is it important to track variants?

Monitoring variants can help find out:

- How the virus changes over time into new variants
- How these changes affect aspects of the virus
- How the changes might impact health.[11]

Variants of SARS-CoV-2

CDC Variants of Concern (VOC)

"A variant for which there is evidence of an increase in transmissibility, more severe disease (increased hospitalizations or deaths), significant reduction in neutralization by antibodies generated during previous infection or vaccination, reduced effectiveness of treatments or vaccines, or diagnostic detection failures."[11]

[Information about reported cases of variants by region and state is available from the CDC.]

Current CDC Variants of Concern in the US (as of 31 August 2021)[10]

Variant *	WHO Label	First Detected	Other Names
B.1.1.7	Alpha	United Kingdom (UK)	20I/501Y.V1
B.1.351	Beta	South Africa	20H/501.V2
P.1	Gamma	Japan/Brazil	20J/501Y.V3
B.1.617.2	Delta	India	20A/S:478K

Note: Current variants of interest (VOI) identified by the CDC include Eta (B.1.525), Iota (B.1.526), and Kappa (B.1.617.1). Another VOI, B.1.617.3, does not have a WHO label at this time.

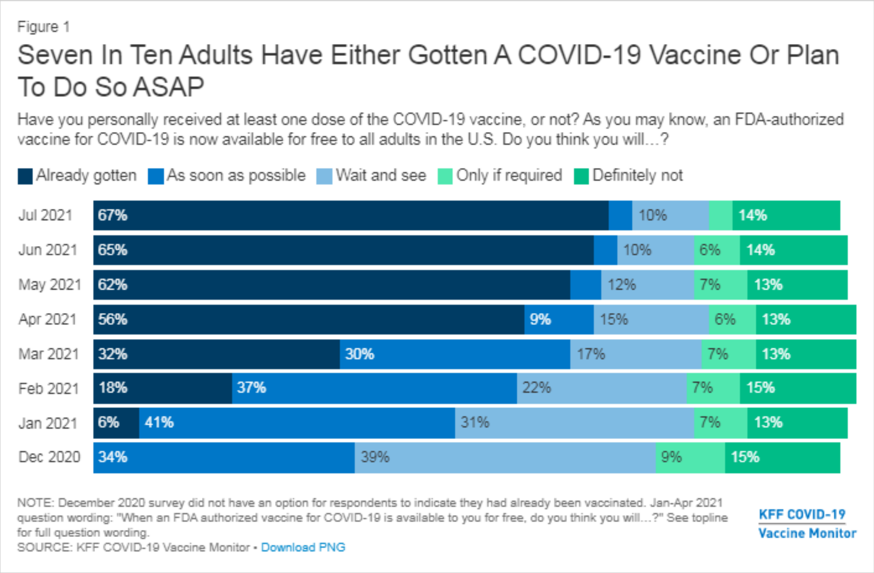
What does neutralization mean?
Neutralization is when antibodies, part of the body's defense, bind to a virus and block infection. Vaccines cause the body to build up the antibodies that inhibit viruses.[12]

SUMMARY OF FINDINGS: SYSTEMATIC SEARCH OF SCIENTIFIC LITERATURE ABOUT SARS-COV-2 VACCINES, VARIANTS, AND VENTILATION

Studies About SARS-CoV-2 Vaccines

Studies About SARS-CoV-2 Vaccines

The Kaiser Family Foundation COVID-19 Vaccine Monitor is an ongoing research project that utilizes surveys and qualitative data to track the US public's attitudes and experiences with COVID-19 vaccines.[13]



[New] Key Findings from July 2021 Monitor

- The share of adults who said they have received a COVID-19 vaccine (67%) or say they will get vaccinated as soon as possible (3%) is relatively unchanged from June.
- The shares of adults who remain unvaccinated is similar to the June Vaccine Monitor and those most reluctant to get the vaccine has remained relatively unchanged since KFF began tracking vaccine intentions at the end of 2020.
- The increase in COVID-19 cases and news of the Delta variant has made some people say they are more likely to wear a mask in public or avoid large gatherings, though this is mainly driven by vaccinated adults.

Studies About SARS-CoV-2 Vaccines

Impact of Vaccines and Safety

- Long-term impacts of the vaccines are still being studied.
- Studies continue to show that COVID-19 vaccines offer protection against the infectiousness, transmissibility, and disease burden of SARS-CoV-2.[14-24, 25-27][New]
  - [New] The U.S. FDA recently amended the emergency use authorizations (EUAs) for both the Pfizer-BioNTech and Moderna COVID-19 vaccines to allow for a third dose in certain immunocompromised individuals, including transplant patients.[28,29]
- Vaccine safety is assessed during the development process and is still continuously monitored.[30-33] While states have expanded vaccine eligibility, surveys continue to show "vaccine hesitancy" remains a concern for ensuring equitable vaccination coverage among all populations.[34,35]
- [New] Rare serious adverse events have been reported after COVID-19 vaccination, including Guillain-Barré syndrome (GBS), myocarditis, and thrombosis with thrombocytopenia syndrome (TTS). During the most recent meeting in July 2021, the Advisory Committee on Immunization Practices (ACIP) determined that the benefits of COVID-19 vaccination in preventing COVID-19 morbidity and mortality outweigh the risks for these rare serious adverse events.[36]

Studies About SARS-CoV-2 Vaccines

- **Vaccine Hesitancy**
  - Factors potentially related to vaccine hesitancy include concerns over vaccine safety, trust in government recommendations, perceived political interference, education, income, race/ethnicity, perceived threat of COVID-19, and [New] experience with racial discrimination.[37-42, 43-44][New]
- **Breakthrough Infections After Vaccination**
  - [New] Breakthrough infections tend to have milder symptoms and shorter periods of illness. One study assessed breakthrough COVID-19 infections among fully vaccinated healthcare workers (N=1,497) and found that 39 had documented infections of SARS-CoV-2. Most were mild or asymptomatic, but some did have persistent symptoms (more than 6 weeks). [45,46]

Studies About SARS-CoV-2 Vaccines

Impact of Vaccines: Subpopulations

- **Older Adults:** In the US, vaccines are effective and there has been a decrease in COVID-19 cases, emergency department visits, hospital admissions, and deaths among older adults, which are the age group with the highest vaccination rates. The elderly population needs to be closely monitored after vaccination and may require earlier revaccination and/or increased vaccine dose [47-49]
- **Pregnant women:** Preliminary findings of vaccine safety (for mRNA vaccines) for pregnant persons did not show any obvious safety signals to pregnancy or neonatal outcomes, but continued monitoring was recommended.[50,51]
- **Rural:** Residents of rural communities are at increased risk for severe COVID-19 outcomes and have lower vaccine coverage (38.9%) than urban populations (45.7%).[52]
- **Adolescents:** Studies have found that the Pfizer-BioNTech vaccine had a favorable safety profile and was highly effective against COVID-19 in 12- to 15-year-olds. On 10 May 2021, the FDA emergency use authorization was expanded to include persons 12 years of age or older based on the data from this study.[53-54, 55-56][New]

Studies About SARS-CoV-2 Vaccines

Health Communication and Misinformation

- Scientists have called for efforts to address miscommunication and misinformation on COVID-19 vaccines and restore trust in health authorities.[57-59] Vaccine acceptance will be impeded by misinformation and poor public health communication strategies.[59-61]
- A rapid expert consultation recommended emphasizing support for vaccines, leveraging endorsements, focusing on hesitant individuals, and engaging communities to increase confidence in vaccines.[62]

Reaching High-risk Populations

- Equitable access to COVID-19 vaccines among racial/ethnic minorities is a key concern as Hispanics and Blacks are less likely to have had at least one vaccine dose compared to Whites and Asians.[63] Researchers have identified that COVID-19 continues to disproportionally impact the Black community, further worsening health disparities already present due to racism and its effects on social and economic factors.[35,64-68] Efforts also need to be made to improve access among persons in low socioeconomic (SES) areas and persons with disabilities.[69]

What Research is Still Needed About SARS-CoV-2 Vaccines? [2,9,70]

- How long immunity lasts for different vaccines
- How well the vaccines keep people from spreading SARS-CoV-2 to others, even without symptoms
- How and when vaccines will be available for children under 12 years old
- How well different vaccines will protect against future SARS-CoV-2 variants
- How well vaccines protect people with weakened immune systems and other sub-populations (elderly, pregnant women, children/adolescents)

Key CDC Resources About SARS-CoV-2 Vaccines

- CDC website - Vaccines for COVID-19
- COVID-19 Vaccine Community Toolkit
- Interim Public Health Recommendations for Fully Vaccinated People
- Key Things to Know About COVID-19 Vaccines
- COVID-19 Vaccinations in the United States

Studies About SARS-CoV-2 Variants

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Studies About SARS-CoV-2 Variants

Spread, Transmissibility, and Infectivity

- Studies have shown that SARS-CoV-2 VOCs are more transmissible than the early strain before major mutations (aka the “wild-type” SARS-CoV-2).[71-81, 82-83][New]
  - A recent global analysis showed that VOCs have rapidly replaced previously common strains in nearly all countries studied. Transmissibility was found to increase 29% for B.1.1.7, 25% for B.1.351, 38% for P1, and 97% for B.1.617.2.[77]
- Research suggests that certain mutations present in VOCs are linked with increased transmissibility and infectivity.[84-88]
- Studies indicate that SARS-CoV-2 VOCs have higher secondary attack rates (spread of disease within an infected person’s family or other group) compared to the wild-type across various settings in which people are in close contact with one another, including households, childcare centers, and gymnastics facilities.[89-91]

Legend:
Names for Variants of Concern in the US*

Variant	WHO Label
B.1.1.7	Alpha
B.1.351	Beta
P.1	Gamma
B.1.617.2	Delta

***as of 31 August 2021[11]**

Studies About SARS-CoV-2 Variants

Outcomes Severity for Variants (compared to wild-type SARS-CoV-2)

- Studies have found both the B.1.1.7 and B.1.351 variants to be associated with increased mortality compared to the wild-type.[92-95]
- A study found that SARS-CoV-2 persisted longer in people infected with the B.1.1.7 variant (16 days) compared to those infected with other variants (14 days).[96]
- Studies have linked the B.1.1.7 and B.1.617.2 SARS-CoV-2 variants to an increased risk of hospital admission.[95,97]
- [New] A recent study in Mesa County, Colorado where the B.1.617.2 variant increased over a 3-month period to become the predominant variant in that county found that incidence, ICU admission, case fatality ratios, and breakthrough infections were significantly higher compared to other counties. [82]
- Specific mutations that have been identified in SARS-CoV-2 variants have been associated with varying severity of COVID-19 illness.[98-100]

Studies About SARS-CoV-2 Variants

Risk of Reinfection

- Case reports highlight instances of reinfection with the B.1.1.7 and P.1 SARS-CoV-2 variants following previous infection with the wild-type virus.[101,102]
- One study reported that the B.1.351 variant has an “unusually large number of mutations,” some of which might be linked to immunoescape (i.e., the virus escapes being stopped by the immune system). Thus, it is unclear whether infection for one SARS-CoV-2 strain offers protection against reinfection by another strain.[103]
- A study found that the B.1.1.7 and B.1.351 variants are more resistant to neutralization (i.e., they are less likely to lose infectivity), which suggests there was evidence of the possibility of reinfection with these strains. [84]
- Despite there being a possibility of reinfection with VOCs, one study showed no evidence of increased reinfection rates in the presence of the B.1.1.7 variant. [75]

Studies About SARS-CoV-2 Variants

Impact of Vaccines on the Variants

- Studies show that current vaccines are effective against most of the current VOCs with a recent preprint finding that the average vaccine efficacy is 86% (95% CI: 65 - 84%) for the B.1.1.7 variant, 61% (95% CI: 43 - 73%) for B.1.1.28 (related to P.1 variant), and 56% (95% CI: 29 - 73%) for B.1.351.[18]
- The Pfizer-BioNTech vaccine is effective against the B.1.1.7, B.1.351, P.1, and B.1.617.2 variants[89-90,91-92] and appears to maintain neutralizing activity against the B.1.1.7, B.1.351, P.1, and B.1.617.2 lineage variants of SARS-CoV-2; however, the B.1.351 and B.1.617.2 variants have shown some resistance to vaccine-elicited antibodies.[104-112]
- The Moderna mRNA-1273 vaccine was found to be effective against the B.1.1.7, B.1.351, and P.1 variants [107,113] and has been shown to maintain some level of neutralizing activity against all circulating SARS-CoV-2 variants; however, the B.1.351 and B.1.617.2 variants have shown some resistance to vaccine-elicited antibodies.[112 ,114-116]

Studies About SARS-CoV-2 Variants

Impact of Vaccines on the Variants (cont.)

- [New] A study assessing the impact of variants (including B.1.1.7, B.1.351, P.1, and B.1.617.2) on antibodies elicited by vaccine mRNA-1273 (i.e., Moderna) showed that all individuals had responses to all variants on Day 43, the peak of response to the 2nd vaccine dose. Antibodies persisted 6 months after the 2nd dose, though at lower levels, complementing current studies on the potential need for booster vaccinations. [117]
- A study examining the presence of neutralizing antibodies (NAbs) in healthcare workers found that 97% of vaccinated participants had detectable NAbs against the B.1.1.7 and B.1.1351 variants compared to participants who had previously been infected with SARS-CoV-2 of whom only 60% had detectable NAbs against B.1.1351. This highlights the need with people previously infected with SARS-CoV-2 to receive vaccinations[118]
- Findings indicated that a single dose of the Pfizer-BioNTech or Moderna vaccines may increase neutralizing activity against the B.1.1.7, B.1.351, and P.1 variants for individuals who were previously infected with SAR-CoV-2.[119-121]

Studies About SARS-CoV-2 Variants

Breakthrough Infections from Variants After Vaccination

- Though existing SARS-CoV-2 vaccines have been found to be effective against emerging variants, there have been reports of breakthrough infections occurring after vaccination.
- A study of 23,000 California healthcare workers who had received at least one vaccine dose reported that 189 people tested positive for SARS-CoV-2. However, most of these cases occurred before individuals were fully vaccinated, and 36.5% of post-vaccination infections (of 115 samples tested) were presumed to be the B.1.427/B.1.429 variants.[122]
  - Although the majority of individuals with post-vaccination infections experienced COVID-19 symptoms, there were only two hospitalizations and no deaths.
- An analysis of the 20 breakthrough SARS-CoV-2 cases in fully vaccinated people in Washington showed that all 20 of the identified cases were classified as VOCs, specifically, B.1.1.7 (40%), B.1.351 (5%) , B.1.427 (10%), B.1.429 (40%), and P.1 (5%).[123]
- [New] A report of a B.1.1.7 variant outbreak in a long-term care facility in Germany indicated that although the majority of vaccinated individuals experienced breakthrough infections, they had milder symptoms and faster time to negative test results than unvaccinated individuals. [124]

Studies About SARS-CoV-2 Variants

Continued Use of Established Mitigation Strategies

- Studies show that it is critical to continue existing public health strategies (e.g., physical distancing, hand hygiene, mask wearing, people quarantining after exposure) to reduce the transmission of SARS-CoV-2 variants while vaccine coverage expands.[125-127]
- A study examining the impact of strengthened social distancing measures in France over the course of a month on the spread of SARS-CoV-2 showed that these measures reduced the effective transmission rate of previously circulating SARS-CoV-2 strains but did not lead to a decline in the spread of the B.1.1.7 variant due to the variant's more efficient transmission.[128]
- A study of the spread of the B.1.1.7 variant in Portugal over a six-week period showed a deceleration in the growth rate of the variant after physical distancing measures were put in place.[129]
- A study examining how well various inactivation strategies work against the B.1.1.7 and B.1.351 variants found that both variants were inactivated by heat, soap, and ethanol, suggesting that existing disinfection strategies remain effective.[130]
- [New] Following an outbreak of SARS-CoV-2 infections which included breakthrough infections, researchers suggested that prevention strategies such as wearing masks indoors should be expanded regardless of individuals' vaccination status.[83]

What Research is Still Needed About SARS-CoV-2 Variants? [2,11]

- How transmissible some variants of SARS-CoV-2 are for certain demographics (e.g., older adults)
- The likelihood of reinfection due to SARS-CoV-2 variants
- How the infectious dose (amount of virus needed for infection) differs between variants and the wild-type lineage
- How these variants may affect existing therapies, such as vaccines

Key CDC Resources About SARS-CoV-2 Variants

- Variants and Genomic Surveillance for SARS-CoV-2
- What You Need to Know About Variants
- Variant Proportions (US COVID-19 Cases Caused by Variants)
- Understanding Variants
- Delta Variant: What We Know About the Science

Studies About the Effects of Ventilation on SARS-CoV-2

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Studies About the Effects of Ventilation on SARS-CoV-2

General Findings

- Many studies used carbon dioxide (CO_2) as a proxy for SARS-CoV-2 to measure the degree of ventilation in a space.[131-136] In other words, testing of ventilation methods with active virus was not conducted.
  - Excess CO_2 concentration has been shown to trend with relative risk of infection. Carbon dioxide concentration can serve as a proxy for infection risk, and there are relatively inexpensive indoor air quality monitoring systems that can be used to monitor CO_2 levels in different rooms of a building.[136-137]
  - However, some researchers have warned against using CO_2 measurements as a proxy, noting that virus-laden particles may behave differently than exhaled CO_2.[138]
- Theoretically, many factors influence whether ventilation is successful in the elimination or decrease of SARS-CoV-2 particles in the air, including activities occurring in the space, occupancy rates, viral load, and various ventilation parameters. [139]
- Air purification or ventilation alone is not enough to decrease virus particles to below guideline levels, but ventilation, purification, and implementation of other mitigation measures (mask wearing, occupancy restrictions, surface cleaning) can reduce risk of infection drastically.[140-142]

Studies About the Effects of Ventilation on SARS-CoV-2

General Findings (Cont.)

- A study focusing on mitigation transmission in classrooms found that ventilation changes were effective at reducing mean transmission risk by 25%, while increasing social distancing from 1.5 to 3 meters decreased transmission risk by 65%.[143]
- Researchers created an app to determine exposure times and occupancy levels based on ventilation, room specifications, and other parameters.[144]
- Modeling research has shown that the probability of infection may be influenced more by how close a person is to someone carrying SARS-CoV-2 than by the amount of fresh air in a space.[145-147]
- HVAC systems tend not to be built for airborne infection control and may only operate at a small fraction of the room air change rate needed to stop virus spread.[146]
  - Air may need to be circulated more frequently in high traffic areas (e.g., communal space and bathrooms).[147]
- Portable air conditioners (window units, mobile air conditioners) may not provide sufficient ventilation to mitigate the spread of COVID-19 and may exacerbate spread.[148]

Studies About the Effects of Ventilation on SARS-CoV-2

General Findings (Cont.)

- Managing places where stale air may accumulate is important to mitigate the spread of COVID-19. Stale air may accumulate around privacy screens or large items and/or work equipment. Smoke visualization and CO_2 meters can help determine where stale air accumulates in a space.[148]
- Although research about the effects of placing dividers between patrons in public spaces (e.g., restaurants) showed limited impact on controlling airborne transmission and that dividers may cause aerosols to gather, the researchers still recommended use of dividers to block direct contact and spread of large droplets between patrons. The researchers also recommended that transmission risk could be reduced by cleaning the spaces created by dividers and leaving them empty (at least 6 minutes) between patrons, as well as using other tactics like increases in air change rates, social distancing, and shortening usages of the spaces.[149]
  - [New] In a classroom study looking at aerosol dispersion from one source, three-sided clear dividers placed around desks resulted in reduced aerosol concentrations at monitors placed on desks. The authors noted that if desks are placed 1.5 meters or less apart, dividers may help to reduce exposure and risk of infection.[150,151]
  - [New] Another study found that a barrier height of at least 60 cm above a desk surface is needed to prevent virus transmission in spaces that are well-ventilated.[152]

Studies About the Effects of Ventilation on SARS-CoV-2

General Findings (Cont.)

- A dedicated outdoor air system (DOAS) is used in many health care settings to provide high rates of ventilation. This unit pumps 100% outdoor air into a space and is used in conjunction with an air-handling unit to heat and cool the air. DOAS are generally placed on rooftops, but new versions of the technology are smaller and more affordable.[153]
- [New] Other methods to reduce the probability of infection in enclosed spaces are heat inactivation, ionization of the air, non-thermal plasma, filter coatings, and chemical disinfectants, but these methods are less utilized than the methods described in this briefing (e.g., air purifiers, HVAC, etc.).[154]
- [New] In a retrospective observational study of a workplace COVID-19 cluster in Italy, researchers found that in spaces that are poorly ventilated and have high occupancy, typical nonpharmaceutical interventions (e.g., distancing of greater than 1 meter, use of plexiglass panels, use of hand sanitizer, and wearing masks when moving about the office but not while seated at a desk) were not sufficient in preventing an outbreak among staff.[155]

Studies About the Effects of Ventilation on SARS-CoV-2

Air Purification

- Various studies have found that air purifiers are effective in decreasing the concentrations of aerosols in a space and that purifiers are most effective was placed close to the emitter.[156-159]
- The most appropriate air purifiers to use against SARS-CoV-2 are those that use HEPA filters, ionizers, or ultraviolet germicidal irradiation (UVGI).[160]
- It should be noted that the effectiveness of air purifiers to reduce transmission risk cannot be measured by CO_2 monitors.[161]
  - CO_2 monitors can be used to gauge the degree of ventilation in a space.[131-136] However, since air purifiers are intended to filter the air of pathogens and CO_2 monitors do not measure the presence of pathogens, the effect of air purifiers on pathogens (e.g., SARS-CoV-2) will not be captured by CO_2 monitors.
- Researchers designed and tested a low-cost air purification device using a box fan, MERV-13 filter, and a cardboard support.[162]
  - Researchers tested this purification device at approximately two air changes per hour, which is typical of a classroom built before 1989. The device reduced the risk of airborne transmission in a classroom setting, lowering the percentage of suspended aerosols in the room to as low as 1% when placed next to the ventilation source.[162]

Studies About the Effects of Ventilation on SARS-CoV-2

Air Purification (Cont.)

- Filters should fit snugly in their housings to mitigate filter bypass and should be replaced according to the instructions on the filter.[163]
- PPE should be worn when replacing air filters to reduce exposure to viral particles.[163]
- There is some evidence that the noise from mobile air purifiers (MAP) may lead to louder speech, which could result in the release of more virus particles. Researchers found that a MAP only successfully removed viral particles in a classroom under very specific circumstances (MAP close to emitter, high volume flow).[164,165]
- Air purifiers have emerged that use a process called photocatalysis. These purifiers do not use filters, but instead use UV light and a semiconductor to destroy viral particles. Research on this type of purifier is still emerging, but their performance is impacted by photocatalyst used, relative humidity, type of virus, viral load, and light source. The advantage of purifiers that use photocatalysis is that they destroy viral particles rather than just trapping them. [166]

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems

- There is a risk that HVAC systems could worsen spread of COVID-19 if not designed or modified to maximize circulation of virus-free air into a space.[158,167,168]
- Displacement ventilation systems, or those “designed to vertically stratify indoor air by temperature (warm air at the top of the room, colder air at the bottom) and remove warmer air” were found most likely to reduce risk of SARS-CoV-2 transmission via HVAC.[130,167,169,170]
- Conversely, another study found that unstable or neutrally stratified air (warm air at the bottom of the room, or no discriminate layers of warm or cold air) reduced the risk of infectious aerosols remaining at one height in the breathing environment.[135]
  - Researchers found that thermally stratified rooms (i.e., separation of warm air toward the top of a room and cooler air toward the bottom) showed higher infection risk than well-mixed rooms where social distancing of greater than 2 meters had taken place. The authors noted that the “infection risk show[ed] multiple peaks” in rooms thermally stratified using displacement ventilation, under-floor air distribution, and displacement nature ventilation (p. 7).[171]

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems (Cont.)

- Ventilation at only one point in a room is unlikely to efficiently remove virus particles in the absence of other precautions (e.g., masks, social distancing, etc.).[172]
- Inadequate or inappropriately positioned ventilation may lead to virus hotspots or increased surface deposition.[167,169,172]
- Incorporation of UV-C light into duct systems was shown to inactivate 99.98% of virus in the air that passed through the duct.[169]
  - Upper room ultraviolet germicidal irradiation (UVGI) can also be used to disinfect warm air as it rises toward the ceiling. UVGI can be used with displacement ventilation or ceiling fans to continually mix and disinfect the air in the room.[168,169]
  - In-duct UVGI used in conjunction with in-duct filters (e.g., HEPA) can significantly reduce viral load in indoor air.[173]

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems (Cont.)

- Increasing air change rates can lead to higher energy costs. These costs can be offset by 'smart' systems, which only ventilate rooms when they are occupied, and also by natural ventilation.[175-178]
  - While many researchers have recommended increasing air change rates to mitigate spread of COVID-19, some researchers caution that an increase in air change rate may lead to more rapid spread of infectious particles to connecting rooms or may less effectively remove particles in certain situations.[173,178]
- Air diffusers and return vents located in such a way that circulated air is contained in one physical space (also called localized flow regimes) may mitigate the spread of contaminated air.[169]
- Outdoor air dampers can be opened beyond the minimum settings to reduce indoor air recirculation (weather and temperature permitting).[163]
- It may be beneficial to run HVAC at maximum outdoor airflow for a period of time (e.g., 2 hours) before a space is occupied.[163]

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems (Cont.)

- Increasing the fraction of outdoor air and using a MERV-13 filter (rather than a MERV-8 filter) were found to be more likely to reduce spread of SARS-CoV-2 between adjoining rooms.[173]
- One study showed that creation of air curtains (i.e., having an air inlet in the ceiling and an air outlet low on the wall) could be better for mitigating transmission risk than a configuration where both inlets and outlets are in the ceiling.[178]
- Experts recommended that exhaust fans in restrooms should operate at all times. They also noted that windows in restrooms with exhaust fans should not be opened, as exhausted air may reenter.[161]

Studies About the Effects of Ventilation on SARS-CoV-2

Historic Buildings & Natural Ventilation

- In a school system in Switzerland, natural ventilation was performed during breaks and decreased the amount of carbon dioxide from 1600ppm to 1097ppm.[132]
  - [New] However, another study found that natural ventilation alone was not sufficient for achieving a CO_2 concentration of below 700 ppm (recommendation provided by Spanish officials) in 54% of classrooms studied.[136]
- In a study of New York City school buildings, transmission was found to be lower in older buildings compared to newer buildings, likely due to “greater outdoor airflow” (i.e., drafts).
  - Transmission rate was also found to be lower in schools with mechanical ventilation (when compared to natural ventilation).[179]
- A study of a historic building in Jeddah (Saudi Arabia) found that the number of windows opened (large windows with cross ventilation) was positively correlated with ventilation rates.[180]

Studies About the Effects of Ventilation on SARS-CoV-2

Historic Buildings & Natural Ventilation (Cont.)

- Findings on the impact of wind speed and direction on ventilation rates and transmission are contradictory. [131,180]
- Research remains inconclusive on whether cross-ventilation or adjacent window ventilation results in better airflow. [181,182]
- Fans can be placed in open windows to increase the effectiveness of natural ventilation. Air should exhaust to the outdoors.[144]
- Windows need to be opened less in winter to achieve the same ventilation rates as open windows in summer due to temperature differences between outdoor and indoor air and wind speed. In winter, windows can be opened from the top to allow cold air to disperse slowly to the bottom of the room, making drafts less noticeable.[148]
- Similar to the research on air purifier placement, opening windows close to the emitter of a pathogen (e.g., a person infected with SARS-CoV-2) is more effective at reducing the concentration of airborne pathogens than leaving the windows closed.[182]

Studies About the Effects of Ventilation on SARS-CoV-2

Effects of Temperature & Humidity

- Because ventilation with outdoor air is more difficult in colder months, researchers have estimated that airborne infection risk is double that of summer months.[134,160,183]
  - During these months, monitoring indoor carbon dioxide as a proxy for ventilation is recommended and should not exceed 1000 ppm.[183]
  - In the absence of carbon dioxide monitoring, attention should be paid to areas where stagnant air is more likely.[183]
- Researchers in another study recommended further research on humidification of air, which could increase the speed at which SARS-CoV-2 particles drop to the ground or surfaces.[184]
- The taller a building is, the more prone it is to stack effect, especially in colder climates. Stack effect occurs when pressure differences between floors cause air to stagnate on upper floors. This effect may also cause a reversal of airflow and contaminants may spread to other areas of the building.[185]
- Some researchers have recommended an indoor relative humidity of 40-60% to prevent respiratory diseases.[161]

What Research is Still Needed About the Impact of Ventilation on SARS-CoV-2?

- Consensus on how best to configure, upgrade, or design ventilation systems to mitigate the spread of SARS-CoV-2
  - What role thermal stratification plays in infection risk
- Whether variants that are more transmissible can be mitigated using the same ventilation methods that are effective for other strains
- How results may differ if ventilation-related studies used SARS-CoV-2 instead of surrogate substances (e.g., carbon dioxide)
- How to best to utilize UVGI (upper room and/or in-duct) to reduce virus particles in a space
- What impact plexiglass barriers and other dividers have on rates of spread and mitigation of SARS-CoV-2[186]
- Regarding natural ventilation, understanding whether opening adjacent windows or windows across from each other is more effective at ventilating a space
- The effect of wind speed and direction on natural ventilation and, consequently, transmission risk
- [New] Best practices for balancing energy efficiency with increased ventilation rates (and increased energy use) to mitigate transmission risk
- [New] The costs and benefits of all ventilation methods that could be used to reduce infection risk.[154]

Key CDC Resources About Ventilation to Mitigate SARS-CoV-2

- Ventilation in Buildings
- COVID-19 Resources for Workplaces & Businesses
- Improving Ventilation in Your Home
- Ventilation and Coronavirus (COVID-19) (Environmental Protection Agency resource)

HOW THIS BRIEFING WAS CREATED (METHODOLOGY)

REALM PROJECT

OCLC

INSTITUTE of Museum and Library SERVICES

BATTELLE

How This Briefing Was Created

- In January 2021, REALM stakeholders developed Phase 3 research questions. An additional question related to ventilation was added in May 2021.
- Battelle developed search strings that included variations of the term “SARS-CoV-2” and novel terms for vaccine and variants using Boolean operators. The Boolean operator “AND” was used to separate SARS-CoV-2 and research question terms, while different variations of the virus name and keywords related to the research question were grouped by category using parentheses and the Boolean operator “OR” (e.g., ["SARS-CoV-2" OR "2019-nCoV" OR "COVID-19"] AND [vaccine OR variant]). Search strings are included in the appendix.
- Battelle developed research question keywords using ad hoc test searches and comparison against known relevant articles. Databases were selected (Scopus, SciTech, Web of Science, and MEDLINE) to provide comprehensive search capacity and inclusion of smaller databases.
- The initial search string included a time criterion to capture articles published in January 2021 and after. Subsequent searches were executed on weekly durations. Note: when the ventilation research question was added in May 2021, articles were searched from 01 January 2021 forward to cover the same time period as the other research questions.

How This Briefing Was Created (cont.)

- Battelle staff reviewed the titles and abstracts of search results to select those most relevant to the research questions for additional examination.
- The DHS Master Question List for COVID-19 and CDC Morbidity and Mortality Weekly Reports (MMWR) were reviewed to verify the completeness of the search results (i.e., to double-check that relevant articles were not missed by the search strings).
- Battelle staff analyzed the relevant articles to identify key subtopics and prioritize high-value articles. Summaries of the articles, organized by subtopic, were presented to OCLC, IMLS, and REALM working groups for feedback.
- Battelle summarized the results for this briefing, which is a cumulative report that builds on prior briefings by adding new relevant research findings published 27 July to 16 August 2021. Additional information was also added from the CDC to provide context on the key topics.
- Battelle will continue to review articles gathered by the search on a regular basis, and this briefing will continue to be updated iteratively with new information.

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APPENDIX: SEARCH STRINGS

Database	Strategy: Vaccines and Variants of SARS-CoV-2
Scopus	((TITLE-ABS (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND TITLE-ABS (spread* OR transmi* OR infect* OR reinfect* OR virulence OR neutraliz* OR sever* OR evad* OR airborne OR aerosol* OR occupation* OR infectiv* OR mortality OR morbidity OR death*) AND TITLE-ABS (variant OR vaccine OR mutat* OR mutant* OR lineage OR immun* OR strain)) AND NOT TITLE-ABS (receptor OR inflamm* OR peptide* OR nanomaterial OR ace2 OR polymerase OR "IgA" OR patient* OR assay* OR ligand* OR protease OR hiv))
SciTech	(ti,ab(coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND ti,ab(spread* OR transmi* OR infect* OR reinfect* OR virulence OR neutraliz* OR sever* OR evad* OR airborne OR aerosol* OR occupation* OR infectiv* OR mortality OR morbidity OR death*) AND ti,ab(variant OR vaccine OR mutat* OR mutant* OR lineage OR immun* OR strain)) NOT ti,ab(receptor OR inflamm* OR peptide* OR nanomaterial OR ace2 OR polymerase OR "IgA" OR patient* OR assay* OR ligand* OR protease OR hiv)
Web of Science	TS=(coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND TS=(spread* OR transmi* OR infect* OR reinfect* OR virulence OR neutraliz* OR sever* OR evad* OR airborne OR aerosol* OR occupation* OR infectiv* OR mortality OR morbidity OR death*) AND TS=(variant OR vaccine OR mutat* OR mutant* OR lineage OR immun* OR strain) NOT TS=(receptor OR inflamm* OR peptide* OR nanomaterial OR ace2 OR polymerase OR "IgA" OR patient* OR assay* OR ligand* OR protease OR hiv)
MEDLINE	(TI (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND TI (spread* OR transmi* OR infect* OR reinfect* OR virulence OR neutraliz* OR sever* OR evad* OR airborne OR aerosol* OR occupation* OR infectiv* OR mortality OR morbidity OR death*) AND TI (variant OR vaccine OR mutat* OR mutant* OR lineage OR immun* OR strain) NOT TI (receptor OR inflamm* OR peptide* OR nanomaterial OR ace2 OR polymerase OR "IgA" OR patient* OR assay* OR ligand* OR protease OR hiv)) OR (AB (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND AB (spread* OR transmi* OR infect* OR reinfect* OR virulence OR neutraliz* OR sever* OR evad* OR airborne OR aerosol* OR occupation* OR infectiv* OR mortality OR morbidity OR death*) AND AB (variant OR vaccine OR mutat* OR mutant* OR lineage OR immun* OR strain) NOT AB (receptor OR inflamm* OR peptide* OR nanomaterial OR ace2 OR polymerase OR "IgA" OR patient* OR assay* OR ligand* OR protease OR hiv))

Database	Strategy: Effects of Ventilation on Spread of SARS-CoV-2
Scopus	(TITLE-ABS (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND TITLE-ABS (spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc*) AND TITLE-ABS (indoor OR office OR "climate controlled" OR ambient OR air OR airborne OR aerosol* OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa)) AND NOT TITLE-ABS (pollution OR particulate* OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR patient OR phenotype OR clinical OR polymerase) AND (LIMIT-TO (PUBYEAR , 2021))
SciTech	(TS=(coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND TS=(spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc*) AND TS=(indoor OR office OR "climate controlled" OR ambient OR air OR airborne OR aerosol* OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa)) NOT TS=(pollution OR particulate* OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR patient OR phenotype OR clinical OR polymerase) AND PUB YEAR= 2021
Web of Science	(TI (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") OR AB (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV")) AND (TI (spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc*) OR AB (spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc*)) AND (TI (indoor OR office OR "climate controlled" OR ambient OR air OR airborne OR aerosol* OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa) OR AB (indoor OR office OR "climate controlled" OR ambient OR air OR airborne OR aerosol* OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa)) NOT (TI (pollution OR particulate* OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR patient OR phenotype OR clinical OR polymerase) OR AB (pollution OR particulate* OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR patient OR phenotype OR clinical OR polymerase)) Date of Publication: 20210101-20211231
MEDLINE	(ti,ab(coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND ti,ab(spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc*) AND ti,ab(indoor OR office OR "climate controlled" OR ambient OR air OR airborne OR aerosol* OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa)) NOT ti,ab(pollution OR particulate* OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR patient OR phenotype OR clinical OR polymerase) Date: After January 01 2021

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